AD-A009 359

EXPLORATORY ANALYSIS OF PREDICTORS OF DIVER PERFORMANCE DECREMENT DURING 3-HOUR, COLD WATER EXPOSURES

W. S. Vaughan, Jr., et al

Oceanautics, Incorporated
Landover, Maryland

March 1975

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD-A009 359
4. TITLE (and Subtitle) Exploratory Analysis of Predictors of Diver Performance Decrement During 3-Hour, Cold Water Exposures		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) W. S. Vaughan, Jr., Oceanautics, Inc. CDR M. B. Strauss, MC, USNR		8. CONTRACT OR GRANT NUMBER(s) N00014-72-C-0309
9. PERFORMING ORGANIZATION NAME AND ADDRESS Oceanautics, Inc. 3308 Dodge Park Road Landover, Maryland 20785		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 197-019
11. CONTROLLING OFFICE NAME AND ADDRESS Engineering Psychology Programs Psychological Sciences Division Office of Naval Research		12. REPORT DATE March 1975
		13. NUMBER OF PAGES 50
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Diver performance
Body cooling
Physical condition
Cold water

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Tasks involving perceptual/cognitive processes were performed by eight Navy divers either during or following 3-hour exposures to both 4.5°C and 15.5°C water. Analysis of performance means had shown significant decrements in task performance as a function of exposure time, but not as a function of water temperature differences. The current analysis was designed to further explore potential relationships between task performance decrement and body cooling, and between body cooling and physical characteristics of the test divers.

DD FORM 1473 1 JAN 73

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Test divers were rank ordered on a variety of indices in each of three categories: physical fitness, body cooling and performance decrement. Indices of physical fitness were based on measures of cardiac, pulmonary and circulatory functioning. Indices of body cooling were based on changes in body heat content as estimated by the standard formula. Indices of performance decrement were based on measures of arithmetic computation accuracy, target detection percentage and time, and navigation problem solving.

Individual differences in body cooling were significantly related to individual differences in four of eight indices of physical fitness: heart rate recovery, respiratory minute volume, forced expiratory volume, and the cold pressor response. Measures of this type appear to have potential as predictors of diver body cooling.

Rank orders based on levels of task performance under baseline conditions were significantly altered by the cold water exposure condition, but the differences in performance could not be attributed to individual differences in body cooling. Within the range of body cooling experienced by these test divers, 3 - 6% reduction of initial levels of body heat content, concommitants of cold water exposure other than body cooling may account for performance decrement in perceptual/cognitive tasks. Potential sources include individual differences in susceptibility to distraction, fatigue and motivational effects.

Technical Report

EXPLORATORY ANALYSIS OF PREDICTORS OF DIVER PERFORMANCE DECREMENT DURING 3-HOUR, COLD WATER EXPOSURES

W. S. Vaughan, Jr.
Oceanautics, Inc.

and

CDR Michael B. Strauss
MC, USNR

Contract Number N00014-72-C-0309
Work Unit: NR 197-019

Prepared for:

Engineering Psychology Programs
Psychological Sciences Division
Office of Naval Research
Arlington, Virginia 22217

Prepared by:

Oceanautics, Inc.
3308 Dodge Park Road
Landover, Maryland 20785

Approved for public release; distribution unlimited.

March 1975

ACKNOWLEDGMENTS

This research was supported jointly by Engineering Psychology Programs, Code 455, Office of Naval Research and by Naval Ship Systems Command, NAVSHIPS 00C3. The authors particularly appreciate the sustained interest and encouragement of Mr. Gerald S. Malecki and LCDR I. C. LeMoyne in furthering research into the problems of diving in cold water.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

EXPLORATORY ANALYSIS OF PREDICTORS OF DIVER PERFORMANCE DECREMENT DURING 3-HOUR, COLD WATER EXPOSURES

I. INTRODUCTION

A. Purpose and General Approach

The reported analyses had two purposes: one was to explore the potential of indices of physical fitness as predictors of resistance to body cooling during cold water exposure; a second was to examine indices of body cooling as correlates of resistance to performance decrement in cold water. The practical application of these inquiries lay in the area of selection of military divers for long-duration, cold-water missions.

The analyses were carried out using data obtained from eight Navy divers who were tested for various cardiac, pulmonary and circulatory functions, trained for three months in a 6-hour task scenario based on a UDT/SEAL team mission involving a wet manned submersible, then tested under two conditions of exposure. Throughout the test exposures, the divers' core and three skin temperatures were recorded. Data collected during the first three hours of these tests were used for the current analyses.

The test scenario required the divers to perform tasks in a wet submersible simulator submerged in a test pool whose water temperature could be controlled. During the 3-hour underwater exposures, the test divers performed tasks representative of submersible pilot and navigator tasks. These included vigilance-monitoring and problem-solving tasks. Upon exiting the water, divers solved abstract map problems which required a series of arithmetic computations. Test divers performed the in-water tasks under two conditions of water temperature, 4.5°C and 15.5°C, and performed the in-air task following 3-hour exposures to each of these water temperatures.

The eight divers were rank ordered according to fitness on each of the cardiac, pulmonary, and circulatory function measures taken prior to cold water testing, and these rank orders were correlated with rank orders based on indices of body cooling in cold water. Results of these correlational analyses were intended to suggest which of the measures of physical fitness potentially predict extent of body cooling in cold water. Next the rank orders based on body cooling were correlated with rank orders based on resistance to performance diminution in cold water. Indices of resistance to performance change were developed by using performance in the warmer water (15.5°C) as baselines against which performance in the colder water (4.5°C) was compared. Results of these correlational analyses were intended to suggest the susceptibility of perceptual/cognitive types of tasks to performance degradation attributable to body cooling.

B. Background of Research

1. Physical Characteristics and Body Cooling

Perhaps the most well-documented physical characteristic related to body cooling is percentage body fat, an index of the diver's natural insulation protecting against heat loss (Keatinge, 1969). The fall in rectal temperature during cold water immersion approximates a linear relationship with skinfold thickness, an index of subcutaneous fat, and large differences in body fat have a substantial effect on body cooling. For example, two fat men (26.7 and 26.8 mm skinfolds) were able to stabilize their rectal temperatures in rather cold water, 10° and 12°C; while two thin men (6.5 and 6.7 mm skinfolds) required water temperatures of 22° and 28°C in order to maintain thermal balance (Cannon and Keatinge, 1960). These findings, however, were obtained from tests with naked subjects immersed to the neck and do not account for two principal differences affecting operational divers. First the diver wears a wet suit for insulation; and second,

the diver breathes gas cooled to approximately the ambient water temperature. Webb and Annis (1966) suggest that respiratory heat loss may account for a significant percentage of total body heat loss when divers breathe cold gas at high pressure for extended time periods. Vaughan and Swider (1972) studied temperature and performance change in Navy test divers, reporting wide individual differences in rectal temperature decline during long-duration cold water exposure in spite of a narrow range of variation among the divers in body fat percentage. Nine Navy divers exposed to 6°C water for four hours experienced rectal temperature reduction in the range 0.6° to 2.1°C although the range of body fat percentage was between 12 and 15 percent.

Under conditions of operational diving, characteristics other than percentage body fat may account for significant individual differences in body cooling, particularly those characteristics related to heat production and to peripheral vascular system control. General level of physical fitness has long been recognized as an important factor in man's ability to acclimate to a cold environment, and a variety of indices of physical fitness have been developed which reflect capacity for heat generation (Adams and Heberling, 1958; Scholander, Hammel, Andersen and Loyning, 1958; Keatinge, 1961; Skreslet and Aerefjord, 1968). Indices are based on cardiac and pulmonary functions which determine the ability of the heart and lungs to efficiently supply oxygenated blood to the tissues and include resting heart rate, maximum working heart rate, heart rate recovery, respiratory minute volume, forced expiratory volume, maximal oxygen uptake, and heart and lung volume (Andersen, 1964).

Capacity of the peripheral vascular system to adjust to ambient temperature changes is a second factor in controlling heat loss and has been estimated by indices based on finger blood flow, finger skin temperature and the cold pressor response (Andersen, 1964; Glaser, Hall and Whittow, 1959; Glaser and Whittow, 1957).

2. Task Performance Decrement and Body Cooling

Accounting for changes in diver performance as a function of cold water exposure appears straightforward for certain task categories. Touch sensitivity of the fingers, for example, can be accounted for by finger skin temperature. At skin temperatures above approximately 8°C, sensitivity thresholds are not significantly affected; between 8°C and 0°C, however, performance falls off sharply for vibratory sensitivity (Weitz, 1941), two-edge sensitivity (Mackworth, 1953; Morton and Provins, 1960), and point pressure sensitivity (Mills, 1956).

Grip strength can be accounted for by temperature of the muscle groups involved. A muscle temperature of 27°C is an optimal value and variation on either side of this value is associated with decreased grip strength (Clarke, Hellon and Lind, 1958). Performance in a variety of manipulative tasks involving manual dexterity deteriorate when finger/hand skin temperature falls below 10°-15°C (Gaydos, 1958; Gaydos and Dusek, 1958; Clark, 1961; Lockhart, 1966, 1968).

Accounting for performance change in "higher order" tasks is not so clear cut; although the assumption is generally made that deterioration of perceptual/cognitive task performance is a function of deep body cooling. One problem is the various ways in which deep body cooling is defined and measured. Definitions of deep body cooling include changes in core temperature estimates, changes in body heat content, and total caloric heat loss. Core temperature estimates are based on measurements from various sites: oral, esophageal, tympanic, rectal and intestinal. Body heat content is an estimate based on variously weighted combinations of skin and core temperature measurements. Measurement of caloric heat loss is a more technically rigorous measure, but the procedure imposes severe constraints on the subject's task performance possibilities.

"Higher order" tasks are not so clearly defined by factor analytic studies as are the perceptual/motor and dexterity tasks. Tests of perceptual/cognitive tasks administered in the water tend to be designed for the constraints of the specific application; they tend to be non-standardized and their technical characteristics such as reliability and factor purity are unknown. Furthermore, where paper/pencil tests are used to assess task performance, results are vulnerable to confounding by changes in dexterity as the hands become cold. To achieve significant changes in deep body temperature conditions, divers are tested over relatively long durations and performance change is confounded with other non-temperature related concommitants of time such as attention lapses, varying standards of performance and other fatigue-related phenomena. Psychological concommitants of cold water exposure are confounded with body cooling as determinants of performance change. Teichner (1958a) first proposed a psychological "distraction hypothesis" to account for performance degradation under extreme temperature and wind conditions independent of changes in skin temperature. Later, Teichner (1968) elaborated the hypothesis as a psychological condition of information overload in novel stimulus environments. This problem is of particular concern in interpreting results of performance-oriented research with novice divers; performance degrades in cold water because the novice diver does not attend to the task as fully as he does in more normal circumstances. Another caution regarding novice diver research is the distortion of visual cues to distance in the water and consequent degradation of performance in tasks requiring hand-eye coordination (Kinney, Luria, and Weitzman, 1968; Kinney, McKay, Luria and Gratto, 1970). Performance effects occuring in the cold water are potentially attributable to inadequate adaptation to distortions of the visual field.

Recently, Vaughan and Andersen (1973) reported an experiment involving experienced, water-habituated test divers wherein the effects of body cooling could be examined independently of other time-related effects. Eight test

divers performed perceptual/cognitive tasks during 3-hour exposures to water at two different temperatures: 4.5°C and 15.5°C. The warmer of the two water exposures served as a control condition or baseline against which to examine the effects of the colder water. Three types of perceptual/cognitive tasks were included in their experiment: arithmetic computation, problem solving, and vigilance monitoring. The arithmetic computation task was presented as generalized map problems wherein distances and rates of travel were transformed to travel times. These problems were administered in air following 3-hour exposures to the different water temperatures, and performance effectiveness was compared to baseline levels established during training. The problem-solving and vigilance tasks were performed during the underwater exposures and hour-to-hour scores were compared in the two temperatures. Average scores for the eight test divers were used to compare performance under the two water temperatures and the results are presented in Figure 1. Three features of the performance data are of interest. First, performance in all perceptual/cognitive tasks was significantly less effective as a function of exposure time under the control condition.* Second, during the second and third exposure hours, only one of the performance means in the colder water was significantly different from those obtained in the control condition. Third, for all tasks performed in the water, the test divers' performance during the first hour in the 4.5°C water was significantly different from the first hour's performance in the 15.5°C water. The test divers apparently were affected by some component of Teichner's (1958, 1968) distraction hypothesis, in spite of their being experienced divers with 30 hours of training in the tasks in 10°C water.

As evidence of the differences in body cooling between the two exposure conditions, Vaughan and Andersen (1973) presented differences in average core and skin temperature. The core temperature measurements were taken

*Significance was defined by the .05 level of risk applied to the results of t-tests of differences between correlated means (Vaughan and Andersen, 1973).

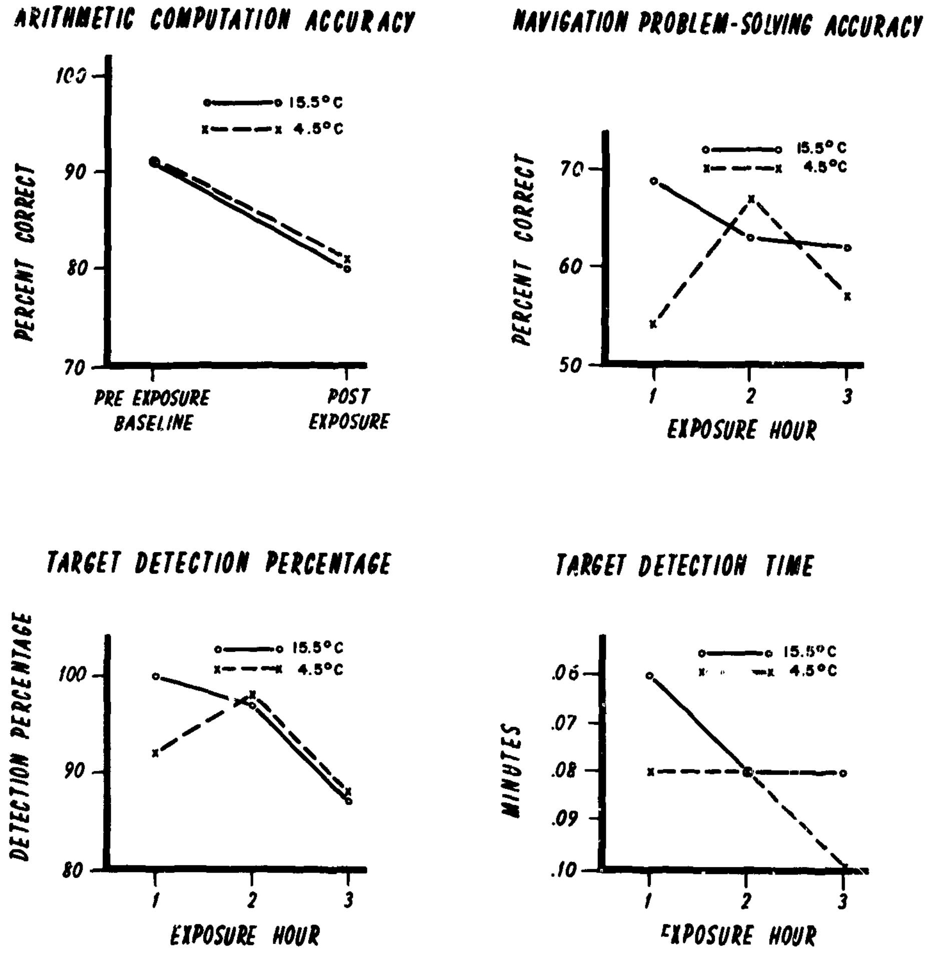

FIGURE 1. PERCEPTUAL / COGNITIVE TASK PERFORMANCE AS FUNCTIONS OF 3-HOUR EXPOSURES TO 15.5° AND 4.5° C WATER

from the diver's intestinal tract via a radiosonde pill swallowed prior to the dive; the skin temperature measurements were taken from three sites: mid-back, medial thigh and upper arm. Mean temperatures of the eight test divers under the two exposure conditions are presented in Figures 2 and 3. These figures show that both core and skin temperature differences during the first hour of exposure were smaller than the differences at hour 2 and hour 3 under the two water temperatures. Differences in performance, however, tended to occur during the first hour and not during the second or third hours of exposure. Performance degradation in cold water in this case would appear to be unrelated to magnitudes of change in core and skin temperatures, and more likely explained by psychological phenomena.

There is the further possibility, however, that analysis of the performance data as averages may be masking evidence of a temperature change-performance decrement relationship among the individual divers. If the eight test divers were ordered on the basis of body cooling and again on the basis of performance decrement, correlational analyses might reveal significant relationships. This general hypothesis was explored in the present treatment of data previously reported by Vaughan and Andersen, 1973.

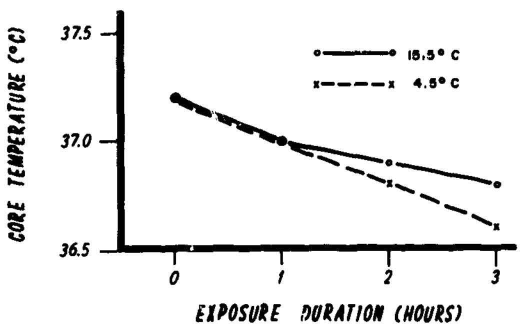

FIGURE 2. AVERAGE CORE TEMPERATURE AS A FUNCTION OF EXPOSURE CONDITIONS

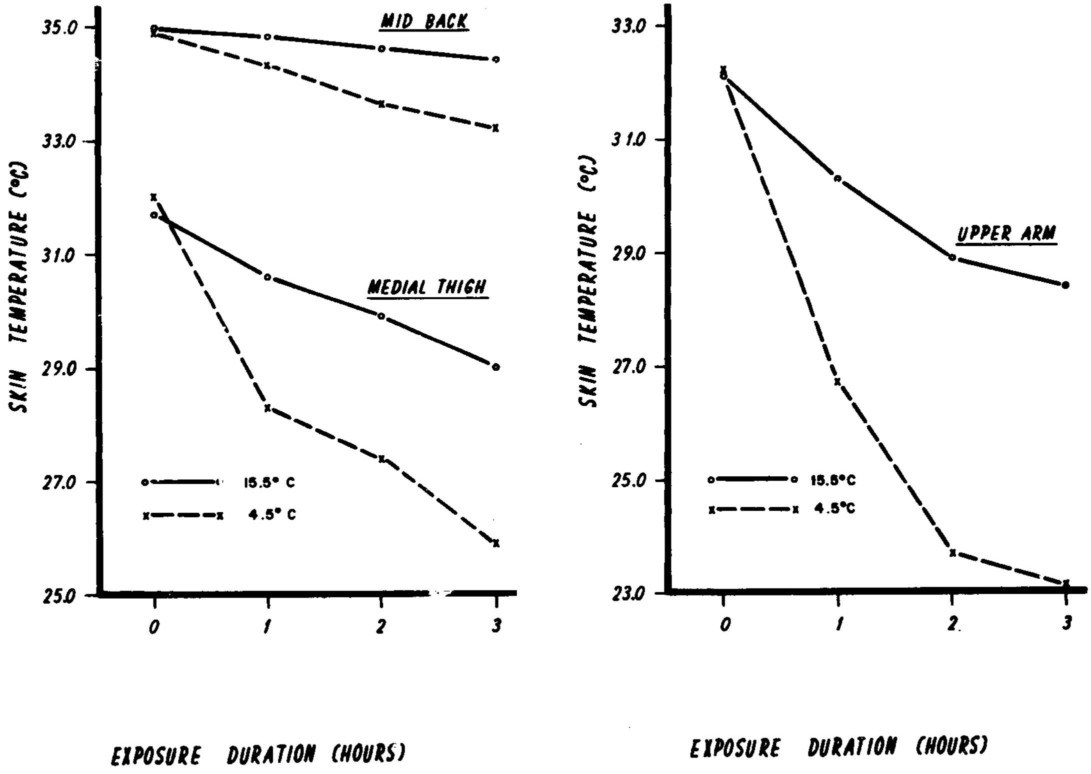

FIGURE 3. AVERAGE SKIN TEMPERATURES AS A FUNCTION OF EXPOSURE CONDITIONS

II. DESCRIPTION OF PREDICTOR, BODY COOLING AND PERFORMANCE VARIABLES

A. Overview of Variables and Method

The rationale for the analyses presented in this report is a two-step hypothesis. First, the better a diver's physical fitness, the better able he is to resist body cooling, either by heat generation or preservation mechanisms. Second, the better the diver's ability to resist body cooling, the less his performance of perceptual/cognitive tasks will degrade as a concommitant of cold water exposure. These hypotheses were explored by the examination of two sets of relationships: between indices of physical condition and body cooling; and between indices of body cooling and performance decrement over 3-hour exposures to both 15.5°C and 4.5°C water. Variables in each of the three main categories: physical condition, body cooling, and performance decrement are listed in Table 1. In the first column are three heart rate-based indices, four pulmonary function-based indices, and one circulatory function-based index of physical characteristics selected as potential predictors of body cooling. Body fat percentage was omitted from this list of predictors since the range was between 11.6% and 14.0% for this sample of divers.* Column two lists the two indices of body cooling developed from skin and core temperature measurements. Both indices are based on changes in body heat content as estimated from skin and core temperature measurements. One was based on degree of change in body heat content as a consequence of the cold water exposure, and the second expressed body heat content change in cold water as a percentage of a "baseline" change in the milder water, 15.5°C. Column three lists the aspects of perceptual/cognitive task performance measured in the two water temperatures

*Body fat percentage was calculated using Pascale's formula for density and Grande's formula for converting density to body fat percentage (Damon and Goldman, 1964).

Table 1. Variables Defining Physical Condition, Body Cooling and Perceptual/Cognitive Task Performance

Physical Characteristics	Body Cooling	Perceptual/Cognitive Task Performance
• Resting Heart Rate • Maximum Exercise Heart Rate • Heart Rate Recovery • Vital Capacity • Respiratory Minute Volume • Forced Expiratory Volume • Mid-Maximal Expiratory Flow • Cold Pressor Response	• Change in BHC pre- vs. post- 3-hour immersion in 4.5°C water • Percentage change in BHC in 4.5°C water relative to change in BHC in 15.5°C water	• Arithmetic Computation Accuracy • Target Detection Percentage • Target Detection Latency • Navigation Problem-Solving Accuracy

and manipulated to generate indices of "resistance to performance degradation." Each index was based on performance change in cold water as a percentage of the change which occurred in the baseline condition.

The eight test divers were rank ordered on each of the variables listed in Table 1. Rank order correlations were computed for all possible pairs of ranks within each of the three main categories in order to estimate the relative independence/dependence of the several indicators of physical condition, body cooling and performance decrement. Then rank orders of each physical fitness variable was correlated with each body cooling variable in order to identify potential predictors of body cooling. Similarly, rank orders based on the body cooling indices were correlated with rank orders based on task performance decrement in order to identify those tasks for which body

cooling might be considered a correlate of performance decrement in cold water.

The statistic used to explore these relationships was the Spearman rank order coefficient of correlation (rho). This statistic is particularly appropriate to an exploratory analysis since it is generally used to indicate the existence or non-existence of relationships rather than to estimate the strength of relationships between pairs of variables (Siegel, 1956). A relationship between two variables is indicated when a sufficiently high value of rho is obtained. In the present case, with eight divers in each rank order, and a risk value of .05, values of rho at least as high as ±.643 were required as evidence of a significant correlation.

B. Physical Characteristics

1. Resting Heart Rate

Resting heart rate was defined as the average number of beats per minute following a 30-minute rest. The lower this value the better the physical condition of the test diver. Resting heart rates for the eight test divers ranged between 40 and 72 bpm, with 40 bpm assigned a rank of 1, and 72 bpm a rank of 8 as shown in Table 2.

2. Maximum Exercise Heart Rate

This index was defined as maximum number of beats per minute following heavy exercise. The lower this value, the more efficient is the heart in supplying oxygenated blood to the tissues. Values were recorded following a 1-minute laddermill exercise and the range was 128 to 164 beats per minute. A rank of 1 was assigned to the diver whose maximum heart rate was 128 bpm and remaining divers ranked accordingly as shown in Table 2.

3. Heart Rate Recovery

This index was defined as the percentage of the rise in heart rate during exercise which is recovered following a 5-minute rest. Good physical

Table 2. Indices Based on Heart Rate

Test Diver	Resting Heart Rate		Maximum Heart Rate After 1-Min. Exercise		Heart Rate Recovery % After 5-Min. Rest	
	BPM	Rank	BPM	Rank	%	Rank
1	56	4	128	1	85	5
2	72	8	132	2	89	8
3	58	5	140	4	100	1.5
4	52	2	136	3	83	6
5	53	3	164	8	90	4
6	64	7	144	5	75	7
7	40	1	160	6.5	95	3
8	63	6	160	6.5	100	1.5

condition is indicated by a high recovery percentage. In the present application, baseline heart rate was measured prior to exercise, then a 1-minute laddermill exercise was conducted and heart rate measured again. The difference in heart rate between the baseline and post-exercise values was defined as the "rise". After 5 minutes of rest, heart rate was measured again and the difference between this value and the maximum post-exercise value was defined as the "recovery". The ratio of the recovery value to the rise value defined the heart rate recovery index. These percentages and rank orders are shown in Table 2. On each index, a rank of 1 indicates the diver in best physical condition, theoretically the best able to generate body heat in response to losses during cold exposure.

4. Vital Capacity

The vital capacity is a static measure of lung volume defined by the maximum volume of air which can be expired following a maximum inspiration. Vital capacity was measured in milliliters and expressed as a percentage of a normative value based on the individual's sex, age and height. Ranks were

assigned according to magnitude of the measure, the largest vital capacity receiving a rank of 1 as shown in Table 3.

5. Respiratory Minute Volume

Respiratory minute volume is a dynamic measure of pulmonary function defined as the volume of air moved into the lungs per minute. Respiratory minute volume was measured in liters per minute and expressed as a percentage of normative values based on age, sex and height. Larger values indicate more efficient lung ventilation potential and ranks were assigned accordingly as shown in Table 3.

6. Forced Expiratory Volume

This index is another dynamic measure of pulmonary function defined as the volume of air which can be expelled from the lungs in a 1-second interval. Volume was measured in milliliters and converted to a percentage with reference to a normative value based on age, sex and height. Ranks were assigned according to magnitude of the measure so that a rank of 1 represents the best condition. Ranks are shown in Table 3.

7. Mid-Maximal Expiratory Flow

This is another measure of dynamic pulmonary function defined as the mean rate of air flow during the middle 50% of a maximal exhalation. Rate of flow was measured in liters per second and expressed as a percentage of a normative value as previously described. Percentages and ranks are shown in Table 3.

8. Cold Pressor Response

The Cold Pressor Response refers to the initial rise and subsequent recovery to normal values of blood pressure in response to immersing a hand in cold water. The test has been suggested as a predictor of cold tolerance on the assumption that fast recovery of blood pressure following the initial rise indicates a responsive peripheral vascular system. Persons who recover more quickly change the heat conserving characteristics of the

Table 3. Indices Based on Pulmonary Functions

Test Diver	Vital Capacity		Respiratory Minute Volume		Forced Expiratory Volume		Mid-Maximal Expiratory Flow	
	% of Norm	Rank	% of Norm	Rank	% of Norm	Rank	% of Norm	Rank
1	138	3	109	5	98	4	127	5
2	133	5	103	6	92	8	125	6
3	136	4	143	1	109	1	219	1
4	150	1	95	7	97	5	173	3
5	115	8	126	3	106	2	201	2
6	122	7	118	4	96	6	124	7
7	132	6	93	8	93	7	116	8
8	141	2	128	2	103	3	160	4

peripheral vascular system more efficiently, thereby providing themselves increased protection against heat loss. Systolic blood pressure tends to be the more sensitive measure of rise and recovery vs. either diastolic pressure or heart rate (Andersen, 1964). Systolic blood pressure, therefore, was used in the current study to develop a predictive index based on the Cold Pressor Response.

In the present application, systolic blood pressure was measured as a baseline condition prior to the immersion of the hand in cold water. Subsequent measures were taken per minute during a 5-minute interval of hand immersion. The recovery percentage was calculated as a ratio of two differences: the difference between the maximum reading and the reading at the fifth minute to the difference between the maximum reading and the baseline:

$$\%\ \text{Recovery} = \frac{BP_{max} - \text{BP at 5 min.}}{BP_{max} - \text{BP Baseline}}$$

The data, indices and ranks for the Cold Pressor Response are shown in Table 4.

Table 4. Cold Pressor Response Index

Test Diver	Pre-Immersion Systolic BP (mm Hg)	Systolic Blood Pressure (During Immersion (Minutes)					% Recovery	Rank
		1	2	3	4	5		
1	106	122	122	104	116	112	62	5
2	132	140	158	158	154	154	15	8
3	140	160	152	148	142	132	140	1
4	120	116	124	128	124	126	25	7
5	104	116	122	110	110	110	67	4
6	122	114	122	120	122	120	102	2
7	110	132	132	126	128	126	27	6
8	126	150	138	130	132	128	92	3

C. Body Cooling

Body cooling was the key variable of the analysis. Measures of physical condition were explored as potential predictors of individual differences in body cooling; measures of perceptual/cognitive task performance were examined as potential correlates of body cooling. The available temperature data consisted of core temperature from the intestinal tract and skin temperature from three sites: upper arm, medial thigh and mid-back. These data were available for each of eight test divers for both 4.5°C and 15.5°C water exposures. Body heat content was estimated by use of traditional formula (O'Hanlon and Horvath, 1970; Webb, 1971).

$$\text{Body Heat Content} = 0.83 \times \text{Weight} \times (0.2\,\bar{T}_S + 0.8\,T_C)$$

The components of the formula are body weight in kilograms, the estimated specific heat of body tissue (0.83), average skin temperature and core temperature. Weights given to the mean skin temperature and the core temperature vary, and so calculations were made with a range of weights: 0.2 and 0.8, 0.33 and 0.67, and 0.5 and 0.5. Furthermore, mean skin temperature could potentially be defined as the unweighted means of the measures from the three body sites, or as the value of the reading at the medial thigh since readings from this site have been found to correspond to mean skin temperatures calculated from seven (O'Hanlon and Horvath, 1970) and ten skin sites (Teichner, 1958b). While use of these formula variations changed the absolute values of body heat content, they did not significantly affect the rank orderings, nor did they significantly alter the relationship between changes in body heat content in the cold water relative to the change in the warmer water. Four rank orderings for change in body heat content were obtained by using 0.2 and 0.8 vs. 0.5 and 0.5 as weighting factors and using unweighted mean skin temperature vs. medial thigh temperature as the estimate of mean skin temperature. Kendall's coefficient of concordance (W) was calculated on the

four rank orders generated by these combinations (Siegel, 1956). W was computed as 0.952, a coefficient significant beyond the .01 level of risk. The formula variations were judged to have produced essentially indistinguishable rank orders.

Two indices of body cooling were developed, a rank ordering based on the degree of change in body heat content between pre- and post-exposure values for the cold water condition, and a rank order based on the percentage change in body heat content in 4.5°C using the 15.5°C exposure as a baseline.

1. Absolute Change in Body Heat Content

Individuals were ranked according to the magnitude of the difference in body heat content between pre-immersion and post-immersion values for the 4.5°C water condition. From Table 5, these values can be seen to range between 72 and 165 kcal. The absolute value of these numbers does not define heat loss since amounts of heat produced by the test diver while in the water cannot be accounted for. Furthermore, the values in Table 5 cannot be transformed into heat loss estimates since Webb (1973) has reported finding no combination of skin and core temperature measures which correlate adequately with calorimetrically determined heat loss.

2. Relative Change in Body Heat Content

As an alternative to the absolute index of body heat content change in cold water, the cold water value was expressed as a percentage of the difference experienced in the control condition. The formula is as follows:

$$\frac{\text{BHC Difference in } 4.5^\circ\text{C} - \text{BHC Difference in } 15.5^\circ\text{C}}{\text{BHC Difference in } 15.5^\circ\text{C}}$$

On the average, the difference in 4.5°C water was an increase of over 100% of the value experienced in 15.5°C. Individuals, however, ranged from 44% to 237% increase vis-a-vis the baseline change. Table 6 presents the rank order based on this index.

Table 5. Index of Body Cooling Based on BHC Change in 4.5°C Water

Test Diver	Change in BHC (kcal)	Rank
1	96	6
2	165	1
3	72	8
4	130	2
5	102	5
6	114	3
7	103	4
8	78	7

Table 6. Index of Body Cooling Based on BHC Change in 4.5°C Water
As A Percent of BHC Change in 15.5°C Water

Test Diver	Change (kcal) in 15.5°C	Change (kcal) in 4.5°C	$\frac{\text{BHC } 4.5° - \text{BHC } 15.5°}{\text{BHC } 15.5°}$	Rank
1	58	96	66%	6
2	49	165	237%	1
3	50	72	44%	8
4	79	130	65%	7
5	52	102	96%	4
6	51	114	124%	3
7	43	103	140%	2
8	40	78	95%	5

D. Perceptual/Cognitive Task Performance

1. Arithmetic Computation Accuracy

Generalized map problems were prepared which required calculation of various time/rate/distance relationships. Test divers were trained in the procedures by which the map problems were to be solved, and the use of preformatted recording forms minimized the possibility of errors from other than computational sources. Each problem varied in the specifics of the time/distance/rate parameters so that the divers could not learn answers, only procedures. Each map problem required 8 additions, 8 multiplications, 6 divisions and 2 subtractions. Both time and accuracy scores were recorded during training to establish baseline performance levels, and immediately following 3-hour exposures to both 15.5°C and 4.5°C water. Accuracy was significantly affected by both exposure conditions when compared to the baseline. Time to complete the problem was not affected by either exposure condition, however, and this was interpreted as evidence that the confounding effects of finger stiffness in cognitive task performance had been eliminated.

An index of arithmetic computation accuracy was developed as a basis for ranking the eight test divers. This index was the difference in accuracy between baseline and post-exposure performance. The diver whose performance declined least was ranked 1, and the diver whose performance declined most was ranked 8. Ranks, therefore, indicate the order of the divers on the characteristic, "resistance to performance degradation". Accuracy scores, differences and ranks are shown in Table 7.

2. Vigilance Monitoring

The test diver's primary task in the manned wet submersible simulator was the simultaneous control of depth and heading via a joystick control. A secondary task was the detection of visual signals randomly presented on a waterproofed CRT as a simulated obstacle avoidance display. Twenty-two signals were presented over the 3-hour test trial according to a prearranged

Table 7. Performance Index for Arithmetic Computation Accuracy

Test Diver	Baseline Accuracy (%)	Accuracy After 3-Hours in Cold Water (%)	Accuracy Decrement (%)	Rank
1	91	72	19	7
2	85	79	6	2
3	92	96	+	1
4	88	81	7	3.5
5	96	76	20	8
6	91	78	13	6
7	92	85	7	3.5
8	95	85	10	5

randomization schedule. The diver's task was to press a button on the joystick control indicating detection. Two aspects of vigilance monitoring performance were recorded: detection percentage and response latency, and both measures were obtained in 15.5°C water and in 4.5°C water for the identical divers. Performance in the warmer water was considered a baseline against which performance in the colder water could be compared, and divers were rank ordered according to resistance to performance degradation in the colder water vis-a-vis the control temperature.

a. Target detection percentage: Defined as the ratio of targets detected to targets presented over the 3-hour exposure interval. This ratio was computed for each diver in both 15.5°C and 4.5°C water temperatures and the difference score used as a basis for rank orders as presented in Table 8. A rank of 1 designates the diver whose performance in the 4.5°C water was most resistant to decline when compared to performance in 15.5°C water.

Table 8. Performance Index for Target Detection Percentage

Test Diver	Detection % in 15.5°C Water	Detection % in 4.5°C Water	Difference	Rank
1	ND	ND	ND	ND
2	95	82	-13	6
3	91	95	+4	2.5
4	95	100	+5	1
5	95	77	-18	7
6	91	95	+4	2.5
7	100	100	0	4
8	100	95	-5	5

b. Target detection latency: Defined as the mean time delay between target onset and target detection for those targets detected during the 3-hour trial. An index of resistance to cold effects was developed by calculating a percentage change in detection latency between the cold and the control water temperature conditions. The formula for percentage change was as follows:

$$\%\ \text{Change} = \frac{\begin{array}{c}\text{Detection Latency}\\ \text{in } 4.5°\text{C Water}\end{array} - \begin{array}{c}\text{Detection Latency}\\ \text{in } 15.5°\text{C Water}\end{array}}{\text{Detection Latency in } 15.5°\text{C Water}}$$

Ranks were assigned on the basis of percentage change magnitude; least change being assigned a rank of 1 and greatest change a rank of 8 so that the rank order index reflected resistance to cold effects. Table 9 presents the mean response latencies in both water temperatures, the percentage change and rank order on the resistance to change index for the eight test divers.

Table 9. Performance Index for Target Detection Latency (Minutes)

Test Diver	Mean Latency in 15.5°C Water	Mean Latency in 4.5°C Water	Percentage Change	Rank
1	.108	.134	+24	6
2	.065	.133	+105	8
3	.070	.091	+30	7
4	.070	.065	-4	1
5	.080	.093	+16	4
6	.062	.073	+18	5
7	.060	.069	+15	3
8	.071	.078	+10	2

3. Navigation Problem Solving Accuracy

The navigation problem solving task required the test diver to monitor changing values of along-track and across-track distances simulating a submersible vehicle's progress over the bottom under pre-programmed conditions of vehicle speed, current set and drift. Using specially designed pencil, ruler, protractor and formatted plotting board,the test diver constructed a vector triangle from the displayed information and determined five values as task outputs: vehicle speed and track over the bottom, current set and drift, and a corrected vehicle heading which would compensate for the effects of the current. The performance scenario included three problems per hour during the 3-hour exposures in both cold and moderate water temperatures. Since each of the five products of the solution process could be scored for accuracy, 45 correct values constituted 100% accuracy. Percentage accuracy in the cold water was compared with percentage accuracy in the control temperature and the difference used as a basis for rank ordering the test divers. Again, the index was intended to reflect a resistance to performance degradation in

cold water. A rank of 1 indicates the test diver whose performance in the cold water was least degraded when his performance in the 15.5°C. water was used as a baseline. Table 10 presents the problem-solving accuracy data and rank order.

Table 10. Performance Index for Navigation Problem Solving Accuracy (%)

Test Diver	Accuracy in 15.5°C Water	Accuracy in 4.5°C Water	Difference	Rank
1	53	47	-6	5
2	51	49	-2	4
3	93	80	-13	7
4	78	49	-29	8
5	67	73	+6	2
6	44	52	+8	1
7	76	64	-12	6
8	58	60	+2	3

III. RESULTS AND DISCUSSION

A. Intercorrelations Within Categories

1. Intercorrelations Among the Predictor Variables

Rank order correlations (rhos) among all possible pairs of the predictor variables were computed and the significant rhos are shown in Table 11.

All three indices based on dynamic measures of pulmonary functioning were significantly intercorrelated; none of the heart rate indices intercorrelated, but heart rate recovery index was significantly related to one of the dynamic measures of pulmonary efficiency: forced expiratory volume. The cold pressor response was significantly correlated with two of the dynamic measures of pulmonary functioning: respiratory minute volume and forced expiratory volume. Lack of significant correlation among the heart rate-based indices is likely to be due to the restricted range of individual differences on these measures; all of the test divers were in the upper ranges of the general population distributions in this aspect of physical condition. In the case of the index, maximum heart rate, the one-minute laddermill exercise most likely did not represent a maximum physical effort for these men. All test divers had vital capacities in excess of normative values and again the high values and narrow range on this characteristic potentially explain its lack of correlation with all other predictors.

2. Intercorrelations Among Indices of Body Cooling

Rank orders based on magnitude of differences in body heat content, pre- vs. post-exposure, intercorrelated significantly across a range of weighting factors for skin and core temperature components of the traditional formulas for estimating body heat content. Mean skin temperature was weighted 0.2, 0.33 and 0.5 while core temperature was weighted 0.8, 0.67, and 0.5.

Preceding page blank

Table 11. Significant Rank Order Correlations Among the Predictors

	RHR	MEHR	HRR	VC	RMV	FEV	MMEF	CPR
Resting Heart Rate								
Maximum Exercise Heart Rate								
Heart Rate Recovery						+0.696		
Vital Capacity								
Respiratory Minute Volume						+0.809	+0.643	+0.833
Forced Expiratory Volume							+0.929	+0.690
Mid-Maximal Expiratory Flow								
Cold Pressor Response								

Rank orders based on body heat content change in cold water as a percentage of the change in more moderate water temperature exhibited the same characteristic: all rank orders were significantly intercorrelated across the range of weightings.

None of the ranks based on absolute change in cold water were correlated with ranks based on change in cold water relative to change in less cold water. It may be that the mechanisms of body cooling in cold water are different from those in more moderate temperatures. For example, respiratory heat loss may become more of a factor in cold than in moderate water; peripheral vasoconstriction, body fat and other heat conserving physical characteristics may become less effective as factors controlling body cooling when the test diver is breathing cold gas over an extended time period.

3. Intercorrelations Among Indices of Performance Decrement

Indices were constructed to represent resistance to decrement during or following cold water exposure vis-a-vis baseline levels of performance. The baseline for arithmetic computation accuracy was defined as an end-of-training performance level; baselines for target detection speed and accuracy, and for navigation problem solving were defined as average performance during test trials in 15.5°C water. None of the rank order correlations among pairs of performance decrement indices was significant. Since the rank orders reflect decrement magnitudes relative to baselines, the lack of significant intercorrelation among them suggests that performance in the four task areas was not comparably affected by cold water exposure. The index "extent of performance decrement" produced different orderings of the test divers for each of the four perceptual/cognitive tasks. High positive intercorrelations would have suggested that the cold exposure degraded performance in the four tasks in the same way, i.e., the diver whose performance changed most on one of the tasks would change most in each of the others. With the present

data, however, performance in each task was changed by different magnitudes in the cold water condition.

A second interesting characteristic of the performance indices was the lack of correlation between rank orders of performance in 15.5°C and 4.5°C water. For each of the four tasks, the test divers were ranked in terms of performance level achieved in each of the two exposure conditions; none of these correlations was significant. This finding suggests that perceptual/ cognitive task performance in moderate water temperatures does not predict performance in cold water. Concommitants of cold water exposure, while significantly diminishing mean performance relative to baseline levels, also reordered the test divers in terms of individual levels of performance effectiveness.

B. Physical Characteristics As Predictors of Body Cooling

Four of the eight physical characteristics selected as potential predictors of body cooling were significantly correlated with change in body heat content during cold water exposure. Rank orders on the physical characteristics were based on fitness, while rank order for body cooling was from greatest to least; i.e., a rank of 1 designated the test diver whose body heat content changed the most during the 3-hour, 4.5°C cold water exposure. As a consequence of these orderings, high negative correlations were necessary to substantiate the predictive potential of the selected indices of physical condition; divers with the highest values on the predictor attributes were expected to experience the least change in body heat content. Table 12 lists the eight indices and indicates the significant rank order correlation coefficients.

These results suggest that measures of physical condition are potential predictors of individual differences in body cooling during cold water exposure. Differences in cardiac, pulmonary, and circulatory functions measures were found to be significantly associated with changes in body heat content

Table 12. Significant Rank Order Correlations Between Indices of Physical Condition and Body Cooling

Physical Characteristics	Change in Body Heat Content During Exposure to Cold Water
A. Cardiac	
1. Resting Heart Rate	
2. Maximum Heart Rate	
3. Heart Rate Recovery	-0.863
B. Pulmonary	
1. Vital Capacity	
2. Respiratory Minute Volume	-0.738
3. Forced Expiratory Volume	-0.833
4. Mid-Maximal Expiratory Flow	
C. Circulatory	
1. Systolic Blood Pressure Recovery (Cold Pressor Response)	-0.738

among this sample of test divers. The findings with respect to cardiac and pulmonary measures probably reflect differences in a more fundamental characteristic, the capacity to generate heat. A more direct measure of heat generating capacity is maximal oxygen uptake and this measure should be tried in future research as a predictor of changes in diver body heat content. The cold pressor response appears worthy of further exploration as an index of circulatory adjustment in retarding heat loss. Body fat percentage, an established factor in retarding heat loss (Keatinge, 1969), was not considered

as a variable in the present analysis due to the narrow range of this characteristic among the divers in the sample.

C. Body Cooling As A Correlate of Performance Decrement

Two indices of body cooling were developed: one based on the difference in body heat content pre- vs. post-exposure to 4.5°C water, and a second based on body heat content change in cold water relative to a baseline change in 15.5°C water. Each of these indices was correlated with the four indices of performance decrement: arithmetic computation accuracy, target detection accuracy, target detection latency and navigation problem solving accuracy. None of the eight correlations was significantly different from zero. Performance in each of these task areas was sensitive to temporal effects; hour-to-hour differences in mean levels of performance during 3-hour water exposures were significant. Each of the four task areas appeared to represent an independent aspect of perceptual/cognitive performance as none of the rank order correlations among the indices were significant. Furthermore, rank orders of performance in the baseline exposure condition in no case correlated with rank orders of performance in the cold exposure; presumably some aspect of the cold exposure differentially affected the divers and reordered their level of task performance vis-a-vis the baseline test conditions. The reorderings could not be attributed to individual differences in body cooling, however.

An interpretation of these findings is that these divers, with higher than average capacities for heat production, were able to maintain body heat content at adequate absolute levels to support performance throughout the exposures; and that other temporal effects were responsible for reordering performance in the cold vs. the baseline exposure conditions. Individuals in this sample of divers may have been differentially susceptible to distraction, fatigue, and motivational effects whose combined effects exerted greater

influence on performance than individual differences in body heat content change. Although differences in body heat content were twice as large in the cold as in the more moderate water temperature, absolute values of post-exposure body heat content were high as can be seen from Table 13. Mean values of body heat content following 3-hour exposures of 4.5°C and 15.5°C were 2279 kcal and 2331 kcal respectively. Changes in body heat content expressed as a percentage of initial values ranged from 1.6 to 3.0% in the warmer water and from 3.1 to 5.7% in the colder water. Although percentage change in the colder water was approximately twice as great as the percentage change in the warmer water, the absolute values of post-exposure body heat content may have been sufficiently high to provide equivalent support for perceptual/cognitive task performance. Percentage decrease in total body heat content to approximately 6% may be an indifference area in accounting for performance decrement in the task areas examined.

Table 13. Body Heat Content (kcal) Change During 3-Hour Exposures to Two Water Temperatures

Test Diver	15.5°C. Water				4.5°C. Water			
	Pre-Exposure	Post-Exposure	Difference		Pre-Exposure	Post-Exposure	Difference	
1	2021	1963	58	2.9%	2022	1926	96	4.7%
2	2866	2817	49	1.7%	2895	2730	165	5.7%
3	2318	2268	50	2.2%	2308	2236	72	3.1%
4	2620	2541	79	3.0%	2613	2483	130	5.0%
5	2312	2260	52	2.2%	2323	2221	102	4.4%
6	2340	2289	51	2.2%	2331	2217	114	4.9%
7	2117	2074	43	2.0%	2123	2020	103	4.8%
8	2475	2435	40	1.6%	2475	2397	78	3.2%
Mean	2384	2331	53	2.2%	2386	2279	107	4.5%

V. REFERENCES

Adams, T., and Heberling, E. J. Human physiological response to a standardized cold stress as modified by physical fitness. J. appl. Physiol., 1958, 13(2):226-230.

Andersen, K. L. Interaction of chronic cold exposure and physical training upon human bodily tolerance to cold. Arctic Aero-Medical Laboratory, OAR, U.S. Air Force, August 1964.

Cannon, P., and Keatinge, W. R. The metabolic rate and heat loss of fat and thin men in heat balance in cold and warm water. J. Physiol., 1960, 154, 329-44.

Clark, R. E. The limiting hand skin temperature for unaffected manual performance in the cold. J. appl. Psychol., 1961, 45(3):193-194.

Clarke, R. S. J., Hellon, R. F., and Lind, A. R. The duration of sustained contractions of the human forearm at different muscle temperatures. J. Physiol., 1958, 143:454-473.

Damon, A., and Goldman, R. F. Predicting fat from body measurements: Densitometric validation of ten anthropometric equations. Hum. Biol., 1964, 36:32-44.

Gaydos, H. F. Effect on complex manual performance of cooling the body while maintaining the hands at normal temperatures. J. appl. Physiol., 1958, 12(3):373-376.

Gaydos, H. F. and Dusek, E. R. Effects of localized hand cooling versus total body cooling on manual performance. J. appl. Physiol., 1958, 12(3):377-380.

Glaser, E. M., Hall, M. S., and Whittow, G. C. Habituation to heating and cooling of the same hand. J. Physiol., 1959, 146-152-164.

Glaser, E. M., and Whittow, G. C. Retention in a warm environment of adaptation to localized cooling. J. Physiol., 1957, 136:98-111.

Keatinge, W. E. The effect of repeated daily exposure to cold and of improved physical fitness on the metabolic and vascular response to cold air. J. of Physiol., 1961, 157, 209-220.

Keatinge, W. E. Survival in cold water. The physiology and treatment of immersion hypothermia and of drowning. Oxford: Blackwell Scientific Publications, 1969.

Kinney, J. S., Luria, S. M., and Weitzman, D. O. Responses to the underwater distortions of visual stimuli. U.S. Naval Submarine Medical Center, Submarine Base, Groton, Conn., July 1968.

Preceding page blank

Kinney, J. S., McKay, C. L., Luria, S. M., and Gratto, C. L. The improvement of divers' compensation for underwater distortions. U.S. Naval Submarine Medical Center, Submarine Base, Groton, Conn., June 1970.

Lockhart, J. M. Effects of body and hand cooling on complex manual performance. J. appl. Psychol., 1966, 50(1):57-59.

Lockhart, J. M. Extreme body cooling and psychomotor performance. Ergonomics, 1968, 11(3):249-260.

Mackworth, N. H. Finger numbness in very cold winds. J. appl. Physiol., 1953, 5:533-543.

Mills, A. W. Finger numbness and skin temperature. J. appl. Physiol., 1956, 9:447-450.

Morton, R., and Provins, K. A. Finger numbness after acute local exposure to cold. J. appl. Physiol., 1960, 15:149-154.

O'Hanlon, J. F., Jr., and Horvath, S. M. Changing physiological relationships in men under acute cold stress. Can. J. physiol. Pharmacol., 1970, 48, 1-10.

Scholander, P. F., Hammel, H. T., Andersen, K. L., and Loyning, Y. Metabolic acclimation to cold in man. J. appl. Physiol., 1958, 12(1):1-8.

Siegel, S. Nonparametric statistics for the behavioral sciences. New York: McGraw-Hill, 1956.

Skreslet, S., and Aarefjord, F. Acclimatization to cold in man induced by frequent scuba diving in cold water. J. appl. Physiol., 1968, 24, 177-181.

Teichner, W. H. Reaction time in the cold. J. appl. Psychol., 1958a, 42(1):54-59.

Teichner, W. H. Assessment of mean body surface temperature. J. appl. Physiol., 1958b, 12(2), 169-176.

Teichner, W. H. Interaction of behavioral and physiological stress reactions. Psychol. Rev., 1968, 75(4):271-291.

Vaughan, W. S., Jr., and Andersen, B. G. Effects of long-duration cold exposure on performance of tasks in naval inshore warfare operations. Landover, Maryland: Oceanautics, Inc., November 1973.

Vaughan, W. S., and Swider, J. S. Crew performance in swimmer delivery vehicle operations. Landover, Maryland: Whittenburg, Vaughan Associates, Inc., 1972.

Webb, P. Measuring the physiological effects of cooling. Human Factors, 1971, 13(1):65-78.

Webb, P. Rewarming after diving in cold water. Aerospace Med., 1973, 44(10):1152-1157.

Webb, P., and Annis, J. F. Respiratory heat loss with high density gas mixtures. Final Report on Contract Nonr 4965(00). Yellow Springs, Ohio: Webb Associates. 1966.

Weitz, J. Vibratory sensitivity as a function of skin temperature. J. exp. Psychol., 1941, 28:21-36.

APPENDIX A

DATA TABLES

Table A-1. Skin and Core Temperatures for Two 3-Hour Exposures to 4.5^{o} C. Water

	Pre-Exposure Temperatures						Post-Exposure Temperatures						$\Delta\bar{T}_s$	$\Delta\bar{T}_c$
	Core	Medial Thigh	Mid-Back	Upper Arm	$\bar{T}_s$	$\bar{T}_c$	Core	Medial Thigh	Mid-Back	Upper Arm	$\bar{T}_s$	$\bar{T}_c$		
1.	37.2	32.5	35.0	33.5	33.7	37.2	36.5	27.0	33.5	23.0	27.8	36.5	5.9	0.7
2.	37.7 37.5	29.5 31.5	35.0 35.0	29.0 31.5	31.9	37.6	36.7 36.7	22.5 24.5	30.0 32.0	19.5 22.0	25.1	36.7	6.8	0.9
3.	37.0 37.5	34.0 31.5	35.0 35.0	32.5 32.5	33.4	37.3	37.0 37.0	26.5 28.0	35.0 34.0	25.0 25.0	28.9	37.0	4.5	0.3
4.	37.0 37.3	32.0 33.5	34.0 35.0	31.5 31.5	32.9	37.2	36.8 36.5	23.0 26.8	31.0 33.0	22.0 22.0	26.3	36.6	6.6	0.6
5.	37.0 37.1	33.0 32.0	35.0 35.0	30.5 33.0	33.1	37.1	36.6 36.3	26.0 28.0	34.5 33.0	23.0 24.0	27.9	36.4	5.2	0.7
6.	37.2	31.0	35.0	34.0	33.3	37.2	36.6	23.8	33.8	23.0	26.8	36.6	6.5	0.6
7.	37.0 37.5	32.3 32.0	35.0 35.0	32.0 32.0	33.0	37.5	36.8 36.8	25.0 27.0	34.7 32.5	21.0 21.5	27.0	36.8	6.0	0.7
8.	37.2 37.2	30.5 33.0	34.0 35.0	32.5 32.5	32.9	37.2	36.7 36.8	28.0 27.0	33.0 34.5	26.0 26.5	29.2	36.7	3.7	0.5

Preceding page blank

Table A-2. Skin and Core Temperatures for Two 3-Hour Exposures to 15.5° C. Water

	Pre-Exposure Temperatures						Post-Exposure Temperatures						$\Delta\bar{T}_s$	$\Delta\bar{T}_c$
	Core	Medial Thigh	Mid-Back	Upper Arm	$\bar{T}_s$	$\bar{T}_c$	Core	Medial Thigh	Mid-Back	Upper Arm	$\bar{T}_s$	$\bar{T}_c$		
1.	37.4 36.9	32.0 34.0	35.0 35.0	32.5 33.0	33.6	37.2	36.8 36.3	28.0 29.0	35.0 34.8	28.0 30.0	30.8	36.6	2.8	0.6
2.	37.0 37.4	28.5 27.5	35.0 35.0	32.5 31.5	31.7	37.2	37.1 36.9	27.0 27.0	34.8 33.5	28.8 25.5	29.4	37.0	2.2	0.2
3.	37.0 37.6	35.0 34.0	35.0 35.0	32.5 33.5	34.2	37.3	37.2 36.7	32.8 29.5	35.0 34.5	30.2 29.0	31.8	36.9	2.3	0.4
4.	37.3 37.2	31.5 31.5	35.0 35.0	33.5 31.2	33.0	37.3	36.8 36.8	27.0 29.0	34.0 34.0	26.7 27.0	29.5	36.8	3.5	0.5
5.	37.1 36.9	31.5 31.8	35.0 34.8	33.0 29.5	32.6	37.0	36.4 36.5	29.0 29.0	35.0 33.0	30.0 27.5	30.6	36.5	2.0	0.5
6.	37.6 37.3	31.0 31.0	35.0 35.0	33.0 31.5	32.8	37.5	37.1 37.0	28.0 29.0	34.5 34.8	28.0 28.0	30.4	37.1	2.4	0.4
7.	37.2 37.5	31.2 32.0	35.0 35.0	32.5 31.5	32.9	37.4	36.8 36.9	30.0 30.0	34.0 35.0	28.5 30.0	31.2	36.9	1.6	0.5
8.	37.2 37.2	31.0 33.5	35.0 35.0	31.0 32.0	32.9	37.2	36.9 37.0	30.0 30.0	33.0 35.0	29.0 28.0	30.8	37.0	2.1	0.2

Table A-3. Change in Body Heat Content During 3-Hour Exposures in 4.5°C. and 15.5°C. Water

Test Diver	Weight (kg)	Weight x 0.83	ΔT_S	$.2\,\Delta T_S$	ΔT_C	$.8\,\Delta T_C$	Q (kcal)
Change in Body Heat Content at 4.5°C.							
1	66.8	55.4	5.9	1.18	0.7	.56	96
2	95.7	79.4	6.8	1.36	0.9	.72	165
3	76.2	63.2	4.5	0.90	0.3	.24	72
4	86.5	71.9	5.5	1.32	0.6	.48	130
5	77.1	64.0	5.2	1.04	0.7	.56	101
6	77.1	64.0	6.5	1.30	0.6	.48	114
7	69.8	58.0	6.0	1.20	0.7	.56	102
8	82.1	68.1	3.7	0.74	0.5	.40	78
Change in Body Heat Content at 15.5°C.							
1	66.8	55.4	2.8	0.56	0.6	.48	58
2	95.7	79.4	2.2	0.44	0.2	.16	49
3	76.2	63.2	2.3	0.46	0.4	.32	50
4	86.6	71.9	3.5	0.70	0.5	.40	79
5	77.1	64.0	2.0	0.40	0.5	.40	52
6	77.1	64.0	2.4	0.48	0.4	.32	51
7	69.8	58.0	1.6	0.32	0.5	.40	43
8	82.1	68.1	2.1	0.42	0.2	.16	40

Table A-4. Heart Rate Increase and Recovery Following A One-Minute Laddermill Exercise

Test Diver	Baseline Heart Rate	Number of Laddermills in 1-minute	End of Exercise Heart Rate	Post-Exercise Heart Rates Per Minute					
				1	2	3	4	5	6
1	76	145	128	116	112	90	86	84	84
2	80	100	132	104	100	100	96	96	96
3	96	134	140	116	108	104	96	96	96
4	64	128	136	124	92	80	80	76	76
5	84	157	164	132	120	92	92	92	92
6	80	134	144	108	100	104	100	96	92
7	50	132	160	84	60	64	56	56	52
8	76	128	160	104	92	80	76	76	76

Table A-5. Index of Vital Capacity

Test Diver	Normative Value (ml)	Measured Value (ml)	% of Norm
1	4235	5836	138
2	4625	6140	133
3	4370	5945	136
4	4640	6949	150
5	4485	5179	115
6	4370	5330	122
7	4385	5767	132
8	4535	6390	141

Table A-6. Index of Respiratory Minute Volume

Test Diver	Normative Value (1/min)	Measured Value (1/min)	% of Norm
1	134	146	109
2	157	162	103
3	143	205	143
4	158	150	95
5	144	181	126
6	143	169	118
7	138	129	93
8	152	194	128

Table A-7. Index of Forced Expiratory Volume

Test Diver	Normative Value (ml in 1 sec)	Measured Value	% of Norm
1	4366	4259	98
2	4788	4426	92
3	4756	5191	109
4	5392	5244	97
5	4073	4319	106
6	4164	3990	96
7	4614	4281	93
8	4987	5143	103

Table A-8. Index of Mid-Maximal Expiratory Flow

Test Diver	Normative Value (l/sec)	Measured Value (l/sec)	% of Norm
1	3.00	3.80	127
2	3.00	3.74	125
3	3.00	6.56	219
4	3.00	5.18	173
5	3.00	6.00	201
6	3.00	3.72	124
7	3.00	3.48	116
8	3.00	4.80	160